200 MAN-YEARS OF LIFE

The Story of Ernest Orlando Lawrence

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. . . . A PHYSICIST WHO HAS CHANGED THE COURSE OF HISTORY

EARLY in 1929 Ernest Orlando Lawrence conceived the principle of the cyclotron in one of those rare flashes of insight that stand out in scientific history. In the course of developing and exploiting the idea—the central preoccupation of the remaining three decades of his life—Lawrence profoundly influenced world science and human history.

Lawrence was the architect of modern large-scale, team-research programs in basic science, exemplified most prominently by the national laboratories around the world. His successful merging of basic research and practical engineering provided a model which, more generally adopted, has escalated the pace of both scientific exploration and technological development. Lawrence and his cyclotron advanced interdisciplinary research and especially the application of physical science to biology and medicine. He and his laboratory strongly influenced the development and improvement of nuclear weapons. The resources of his laboratory were important in the initiation of a new policy of Federal investment in basic science in the United States immediately after the war.

Many factors were responsible for Lawrence's enduring impact. He took

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up physics as a substantial indigenous American science began to rise. He was not only a part of that movement, but also was in the forefront of American science's ascent from a secondary status to a position of world leadership. His cyclotron came into the scientific field when the atomic nucleus was ripe for plucking; and his accelerators were the most efficient machines for the harvest. But above all in the catalog of factors stands Lawrence himself—his character, his diverse talents, and his personality. What were Lawrence's origins? What kind of man was he? How did he use his talents to achieve so much?

Lawrence came out of the heartland of the nation, the descendant of educated Norwegian immigrants who braved the frontier before the middle of the last century. The founder of the family in America was Grandfather Ole Lawrence (Lavrants), who, fresh from Flatdal in Telemarken, Norway, settled in Madison, Wisconsin, in 1840, and took up his profession of teaching among the frontier settlers. Lawrence's father, Carl, after graduating from the University of Wisconsin in 1894, became a teacher of Latin and history in South Dakota. Carl soon became superintendent of public schools in Canton, and ultimately assumed the presidency, first, of Southern State Teachers College in Springfield, South Dakota, and subsequently of Northern State Teachers College at Aberdeen, S. D. While at Canton in 1900, Carl married Gunda Jacobson, a pretty second generation Norwegian girl and a high school mathematics teacher.

The character of the parents and the nature of the family environment reveal much about Lawrence the scientist. Both parents were people of high principle. Carl was fired from a school administrative position during World War I for resisting anti-German pressure to remove the German language from the curriculum. Gunda, upon accepting Carl's proposal of marriage, had conscientiously quit her teaching post and obtained a position as a servant in order that the apprenticeship in homemaking would make her a better wife.

Canton was a village on the Big Sioux River. When Ernest began life there on August 8, 1901, the echoes of the taming of the Great Plains had hardly died away. And all his life the uncomplicated imprint of the small towns of the Plains was to remain in his thinking and his personality.

The parents mingled principle and strictness with love and understanding for Ernest and their second son, John Hundale. Gunda, a devoted Lutheran, taught her sons the traditional values of pioneer America—honesty, morality, and the fear of God. Although the Lawrences were never poor, a teacher's salary kept the family in modest enough circumstances to provide abundant opportunity for the boys to learn at first hand the parental values of frugality, hard work, initiative and self-reliance.

For the most part, Ernest's childhood and youth were not remarkable. He grew tall at an early age—ultimately his height was six feet two inches—and was so slender that he earned the nickname, "Skinny." He had the clear blue eyes and luxurious thatch of blond hair of his Norwegian ancestors. Astigmatism forced him to wear glasses at an early age, giving him an owlish look. As a high school boy, he was remembered by townsmen as "tall, ungainly and slump-shouldered." For a time he played tackle on the football team, but his slight physique forced him to retire—with a lifelong lump the size of a walnut high on his left forehead. His quick reflexes, however, served him well in tennis, a sport in which he excelled until the year of his death. Through high school, he was a careless dresser, had no "girl friends," and was socially indifferent. An early reticence, which prevented him from expressing himself effusively, remained with him all his life.

The future scientist showed few signs of genius in his school work. He earned good high school grades in the sciences—scores in the 90's and high 80's—but he had to settle for marks in the 70's in English, his poorest subject.

A number of traits that were important in his later achievements, however, did show up early. In some ways he was precociously mature. His mother frequently remarked, "Ernest was born grown up." He had a "knowing" quality—an instinctive insight about people and situations and a ready recognition of what was important.

The young Lawrence exhibited an almost compulsive industry, sustained by boundless energy and complimented by an unusual single-mindedness. He was always in a hurry. By taking a heavy schedule of courses, he completed high school in three years instead of four, graduating at the age of 16 in the spring of 1918. Compelled to earn his own spending money, he applied himself with initiative, and intense energy. In the summers he worked on the surrounding farms—as a cornhusker, laborer and general handyman. He collected tickets at the state fair, worked as a night clerk in a hotel, and did odd jobs for the traveling lecturers of the Chautauqua circuit. He showed precocious business acumen by working his way into leadership of a troop of youthful door-to-door aluminum ware salesmen, and trading his way up from an old Model-T Ford to a brand new car.

Like many thousands of American

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[Editor]

youngsters, young Lawrence tinkered his way through the youth of American technology. He built and operated telegraph and crystal sets, and was forever taking Model-T's apart. Among his adolescent friends, he earned the reputation for being the one who, when everyone else failed, could make things work.

One of his boyhood friends in Canton was Merle Tuve, who was also to become a great American scientist. The two boys discovered a recent electrical engineering graduate of M.I.T., Vern Kennedy, living in town. The youths induced Kennedy to teach them the elementary facts of electricity after school. They applied their knowledge to the construction of a wireless receiving set, and became ham radio addicts.

Lawrence entered college with his eyes on a career in medicine—a field in which he never lost interest. Gunda considered her son—just turned 17—too young to go into the "wickedness" of the State College. So in the fall of 1918, she sent him to the smaller and more cloistered St. Olaf's, a small college with Lutheran-Scandinavian ties, in Northfield, Minn. The war was on, and the campus had a Student Army Training Corps program—for which Lawrence was too young. Sensitive to his youth and somewhat uncertain of his goals, he spent an unsettled year. Among other things, he wound up with a D in mathematics.

In the fall of 1919 he transferred to the University of South Dakota, at Vermillion, S. D., and it was there that an interest in physics was awakened in him by a great teacher, Dean Lewis E. Akeley. Lawrence came to Akeley's attention by asking permission to build a radio broadcasting station—an ambitious project for a small college in 1919. Akeley gave his consent, but advised the youngster to take some physics. Lawrence, majoring in chemistry and with medical school in mind, demurred.

But Akeley, seeing something worth while in Lawrence, was persistent, persuasive, and dedicated. Before the school year was out, Akeley won Lawrence over. During the first six weeks of the summer Akeley and Lawrence worked together a large part of every day. Akeley lectured on physics. Lawrence, the only student, took notes and examinations. When the period was over, Lawrence had completed a year of physics—and under pressure from Akeley went on to take more.

Lawrence graduated in chemistry in 1922—still intent on medicine. But a fellowship and the importunities of Merle Tuve, whose family had moved to Minneapolis, brought Lawrence to that city and to the University of Minnesota.

If Akeley waggled the bait of physics before Lawrence, W. F. G. Swann, under whom Lawrence began studying at Minnesota, set the hook. Swann, a pioneer in cosmic ray research, had an enormous impact upon Lawrence. From Swann, Lawrence learned electromagnetic theory—a major basis of his later career—and earned his master's degree in the spring of 1923. In that year Lawrence got his first glimpse of accelerator potentials and problems—for even then Swann was working on an electrostatic generator.

Swann moved to Chicago in the fall of 1923—and Lawrence went with him. It was at Chicago—alive with new ideas and great physicists—that Lawrence was finally and completely caught up in the excitement and fascination of research. He occupied a laboratory next to Arthur Compton's, and he sat up all night in Compton's laboratory during the definitive experiment demonstrating the Compton effect. Later, in "Atomic Quest," Compton was to say of Lawrence: "He had an extraordinary gift of thinking up new ideas that seemed impossible of achievement and making them work. In our conversations in the Laboratory our relations had been more those of research colleagues than those of student and teacher."

For Lawrence, all doubts about the future were resolved: science was the life for him. He poured his abundant energy into the Laboratory. Nights, Saturdays, Sundays, holidays—time had no meaning if there was something to be done in the laboratory; and more often than not, there was. It was a pattern Lawrence followed for the remainder of his life.

After a year at Chicago, Swann moved on to Yale. Lawrence followed. There he did his thesis research on the fine structure of the photoelectric effect in potassium, receiving the Ph.D. in the spring of 1925. The thesis, containing new detail of the photoelectric effect, marked Lawrence as an outstanding newcomer, and he was supported by National Research Council Fellowships for two years after he received his degree. In 1927, he was appointed to an assistant professorship on the Yale faculty.

Early in 1925, in an interlude between completion of his thesis and his oral examination, Lawrence filled in some spare time by tinkering with cathode ray tubes for transmitting and receiving images. A friend was impressed by this primitive television "invention," and induced Ernest to approach the Bell Telephone Laboratories. There he was shown patents on most of the work Lawrence had done independently. But although science consumed his time in the years that followed, he maintained a lively interest in television. As commercial television started to get a foothold in the post-war period, Lawrence was intrigued by the knotty problem of color TV. In the early 1950's, he started experimenting, in his garage, with a single gun color TV tube. The principle gave promise of a simple, flexible, inexpensive, high fidelity color tube. With a friend he formed a partnership for development of the tube in affiliation with Paramount Pictures, Inc. Recently, a Japanese firm (Sony) announced that it had undertaken production of small color TV sets using the Lawrence tube.

Although the cyclotron has obscured his early research, Lawrence did outstanding work in his pre-accelerator period. At Yale he measured the ionization potential of the mercury ion, which permitted calculation of the Planck constant, h, the fundamental constant of quantum theory and one of the four most important universal constants in nature. He and J. W. Beams developed a successful method for obtaining time intervals as small as three nanoseconds. He developed a new and precise method of measuring e/m, the ratio of the charge to the mass of an electron—a method later carried to an elegant state of perfection by an early student of Lawrence at Berkeley, F. G. Dunnington.

Lawrence grew and prospered at Yale. By the standards of the day he was treated munificently. The idea that Lawrence could consider the University of California's offer of an associate professorship for the fall of 1928 at a salary reduction of $300 from his stipend of $3600 was greeted with disbelief in New Haven—and not without reason. In the academic world, Yale

This photograph was taken by Watson Davis of Science Service at Berkeley in September 1930, when Dr. Lawrence described his relatively crude apparatus based on the resonance principle of the instrument later called the cyclotron. Dr. Davis wrote in the opening paragraph of his news bulletin as follows: "The production of atomic projectiles of tremendous speed, capable of smashing the hearts or nuclei of gold and other elements, perhaps transmuting them into other substances or releasing large quantities of atomic energy, is promised by a new experiment reported to the National Academy of Sciences at the meeting here by a young University of California professor of physics, Dr. Ernest O. Lawrence, and his associate, Dr. N. E. Edlefsen."

This photograph shows Dr. Lawrence some 18 years ago after the announcement made in 1930. He is at the ion source of the 184-inch cyclotron at the University of California Radiation Laboratory in Berkeley. During the interim between the two photographs shown here, Lawrence had been awarded the Comstock Prize of the National Academy of Sciences, the Cresson Medal of The Franklin Institute, and the Hughes Medal of the Royal Society of London. In 1939 he was selected for the Nobel Prize in physics.

This picture was taken about 10 years before his untimely death in 1958.

was a leader, and membership on the faculty was a high honor. California, a far western state university, was not then considered a serious competitor for faculty. Lawrence was assured he would be burying himself at Berkeley.

But to Lawrence security and academic prestige had less meaning than elbow room. He wanted to move fast and free. California meant the opportunity of complete freedom in research and a light enough teaching load to allow time for it. So in the fall of 1928 Lawrence turned his back on a virtually assured career of distinction. Like his ancestors he faced west, with a mixture of uncertainty and challenge.

Meanwhile, Lawrence had been troubled by this question: To what field of physics should he commit himself? As he left Yale for Berkeley, Lawrence had made his decision. To Lawrence, as he said later, it was clear from the work of the Rutherford school that "the next great frontier for the experimental physicist was surely the atomic nucleus."

Rutherford did his great work by bombarding nuclei with alpha particles from radium. But there were limits on the energy, the variety and the intensity of particle beams that could be obtained from radium. So physicists in Europe and America considered means for overcoming these limits by the acceleration of particles.

In the fall of 1928 the major approaches to laboratory acceleration of particles were transformers and rectifiers, the surge generator, the electrostatic generator, and the Tesla coil. To Lawrence, they all seemed complex, costly, and, most important of all, they had serious limitations on the energy that could be achieved. All of these methods required the use of high voltages and no insulators could withstand the high voltages required for the energies Lawrence had in mind. Lawrence's head was full of these ideas in February, 1929. In his Nobel Lecture, years later, he recounted how he elaborated the concept of the linear accelerator and discovered the cyclotron principle:

"One evening early in 1929 as I was glancing over current periodicals in the University library, I came across an article in a German electrical engineering journal by Wideroe on the multiple acceleration of positive ions. Not being able to read German easily, I merely looked at the diagrams and photographs of Wideroe's apparatus and from the various figures in the article was able to determine his general approach to the problem—i.e., the multiple acceleration of the positive ions by appropriate application of radio frequency oscillating voltages to a series of cylindrical electrodes in line. This new idea immediately impressed me as the real answer which I had been looking for to the technical problem of accelerating positive ions, and without looking at the article further I then and there made estimates of the general features of a linear accelerator for protons in the energy range above one million volt electrons. Simple calculations showed that the accelerator tube would be some meters in length which at that time seemed rather awkwardly long for laboratory purposes. And accordingly, I asked myself the question, instead of using a large number of cylindrical electrodes in line, might it not be possible to use two electrodes over and over again by bending the positive ions back and forth through the electrodes by some sort of appropriate magnetic field arrangement. Again a little analysis of the problem showed that a uniform magnetic field had just the right properties—that the angular velocity of the ions circulating in the field would be independent of their energy so that they would circulate back and forth between suitable hollow electrodes in resonance with an oscillating electrical field of a certain frequency which now has come to be known as the 'cyclotron frequency.'"

The first attempt to explore the resonance principle of the cyclotron was made in the spring of 1930 when one of Lawrence's students, Nels Edlefsen, constructed two crude models —truly "sealing wax and baling wire" gadgets with vacuum chambers about four inches in diameter. One showed some evidence of working.

Lawrence made the first public announcement of the new method at the meeting of the National Academy of Sciences held in Berkeley in September, 1930, where he demonstrated the tiny model.

That fall, M. Stanley Livingston, another graduate student, undertook the construction of a more sophisticated model as his thesis. He built a chamber of brass and sealing wax 4½ inches in diameter. This instrument had all the major features of later cyclotrons. On January 2, 1931, this tiny cyclotron, using a potential difference of 2000 volts, accelerated hydrogen molecular ions to an energy of 80,000 electron volts. This marked the first successful operation of a cyclotron.

A nine-inch cyclotron was built, and then an 11-inch instrument which in 1932 accelerated hydrogen ions to 1.25 million electron volts (Mev)—surpassing for the first time the magic number of 1 Mev in particle acceleration. With this instrument, Lawrence and his colleagues confirmed the notable work of Cockroft and Walton with lithium, accomplishing the first artificial disintegration of the nucleus in the U. S.

A lesser man would have rested on his laurels, at least momentarily. Indeed, more than one colleague wondered aloud why Lawrence would want to go to higher energy. But to Lawrence this was only a beginning. The disintegration of light nuclei, such as lithium, added significantly to scientific knowledge. But 1 Mev particles could not cause reactions in the heavier nuclei—the Coulomb barrier was too great for penetration by ions of such low energy.

Up to this point, Lawrence, although exploring a new technology, had been working pretty well within the bounds of common experience in the way of laboratory equipment. Now he wanted to reach out into the multimillion volt energy range—where he felt the nuclear hunting would be really good. To Lawrence, a slight improvement in an existing technique was dull and uninteresting. But a tenfold leap—that was worth a man's time. Lawrence fished only for the big ones.

To go to the multi-million volt range, Lawrence needed a huge magnet by the laboratory standards of the day. Professor Raymond T. Birge, Chairman of the Berkeley physics department, emeritus, later observed: ". . . the construction of the much larger instrument now needed meant moving from the realm of physics into that of engineering; and that is just where most physicists would have stopped. Not so with Dr. Lawrence."

Size and complexity, however, were not the only problems. In those days science existed in penury, and a grant of $1000 was handsome. In this environment Lawrence proved to have a remarkable gift for getting support, and it was one of the major factors in his success. Although some casual observers put him down as a "promoter," the term is superficial as applied to Lawrence. History has shown that the basis for his support was good ideas. He had complete faith in the need for exploring those ideas; his enthusiasm was infectious; and he inspired confidence among responsible people. With the funds he received, he produced handsome research results, perpetuating the cycle.

But in 1931 he was just beginning to build his reputation. For the next step in energy he needed a huge magnet. The cost seemed almost prohibitive in view of the level of support available. At this stage it almost appeared that money would put a ceiling on Lawrence's ambitions.

Fortune intervened. There was a then-gigantic, 75-ton magnet lying unused in a Palo Alto, California, warehouse. It had been built by the old Federal Telegraph Company during World War I for a radio transmitter ordered by the Chinese government, but it was obsolete before delivery was possible. The "white elephant" was given to Lawrence who installed it at Berkeley in October, 1931, in an old frame structure which was christened the "Radiation Laboratory."

To his attack on the tricky cyclotron technology, Lawrence brought the bone-deep knowledge of electromagnetic theory which had shown through so clearly in his conception of resonance acceleration. His method was a mixture of empiricism, art, boldness, faith and sweat. He did not hesitate to venture into territory where no theory existed as a guide; and he continued to be blessed with his youthful ability to "make things work." Nor was he alone. He attracted to Berkeley young men of his own breed, to whom he imparted his own enthusiasm and confidence. Together they flew in the face of the "impossible." Time after time, the "impossible" was achieved.

While constantly striving for higher energy, Lawrence also worked to increase beam intensity. In 1933 the great G. N. Lewis, dean of the Berkeley chemistry faculty, isolated heavy hydrogen and gave some to Lawrence. Deuterons, proved to be much more easily accelerated than protons, and primary beam intensity rose markedly.

Deuterons greatly increased the usefulness of the cyclotron in another way. By the fall of 1933 Lawrence had found that deuterons produce a much more intense secondary beam of neutrons than protons. Soon the intensities of the primary beams and the secondary neutron beam were many orders of magnitude greater than any possible radium source could produce.

By 1934 Lawrence's single-minded determination to forge a truly useful tool had paid off. As reliability of operation improved, research time rose, and Lawrence was ready to exploit the rich nuclear world then evolving. He was delighted with the research opportunities offered by the discovery of artificial radioactivity in 1934. At the same time he was naturally rueful that the discovery had not been made in his laboratory.

"Indeed," he observed later in his Nobel Lecture, "looking back, it is remarkable that we managed to avoid the discovery of artificial radioactivity prior to their (Joliot-Curie) epoch-making announcement: for we tried at first to use Geiger counters in observing nuclear radiations produced by the cyclotron and observed that their background was always variable and large. In those days Geiger counters had the reputation of being unreliable and, rather than looking into the matter of their apparent misbehavior, we turned to ion chambers and linear amplifiers to observe heavy particle reactions. Of course, the Geiger counters were simply being faithful to duty and recording the radiations from the artificial radioactive substances and this became apparent immediately after the Joliot-Curie announcement."

Upon hearing of the discovery, Lawrence, Livingston and others immediately exposed a large number of the elements to the cyclotron beam, and observed activities in nearly all. This was the beginning of one of the richest areas of research with the cyclotron. The intense beam insured production of much larger quantities of radioisotopes than could be obtained from radium bombardment. The identification of isotopes was made easier, and sufficient quantities of radioisotopes could be produced for research in many fields and for the diagnosis and treatment of disease. For years, hardly a week passed without the discovery of one or more radioisotopes at Berkeley; the number amounted to many scores before World War II. Among them were such familiar ones as carbon-14, iodine-131, iron-59, and hydrogen-3 (tritium).

Lawrence realized his cyclotron was more than just another instrument of physics research, and he actively promoted the use of the machine and its products among other scientists. He sent the first research quantity of a radioisotope, produced in 1934, to George de Hevesy, in Copenhagen, for the honor of doing the first tracer study with an artificial radioisotope. De Hevesy, who pioneered the tracer technique with natural radioisotopes of lead, traced the path of phosphorus-32 in rats. Lawrence engaged the interest of physicians, biochemists, physiologists and agricultural and engineering scientists in the use of radioisotopes. And they began pioneering studies which caused the Nobel committee in 1939 to call special attention to these applications in its citation of Lawrence.

In the summer of 1935, Ernest's brother, John, by then a full-fledged research M.D. at Yale, visited Berkeley. The intense beam made it possible for the young physician to do the first experiments on the biological effects of the neutron beam, about which nothing was known. He found neutrons to be five times as destructive of tissue as x-rays. The finding had two major results. First, it precipitated the development of safety measures which provided important background for safe practice in the nuclear age. Second, it initiated the now-important exploration of heavy particle high energy beams in biological research and treatment of disease.

In 1937, with the 37-inch cyclotron performing efficiently, (6.3 Mev deuterons) and yielding good research, Lawrence's gaze turned again to the horizon. As usual, he wanted higher energy. The deuterons and alphas of the 37-inch were not energetic enough to cause reactions in the heaviest elements. In addition, the rich frontier of radioisotopes application required expanded production, and only a cyclotron could produce them in quantity. Finally, a neutron beam of higher energy showed promise in cancer treatment. By mid-1939 a 60-inch cyclotron, with a 225-ton magnet, had joined the 37-inch on the firing line and was accelerating deuterons to 16 Mev and alpha particles to 32 Mev.

By this time, Lawrence's cyclotron and his Laboratory showed characteristics which were to have a big impact on the world of science. It was the prototype of the big laboratory—of research on the grand scale—now emulated the world over. It was interdisciplinary—often scientists in several fields had to pool their skills to do an experiment. Lawrence had successfully married engineering to science, to create a new accelerator technology. The field of nuclear chemistry in the United States was born in the shadow of the cyclotron, the leading exemplars including W. F. Libby and Glenn T. Seaborg. Lawrence produced radioisotopes and distributed them around the world to eager and grateful scientists in physics, chemistry, biology, medicine and engineering. Visitors and students at Berkeley had taken cyclotron know-how and blueprints to institutions across the country and to other nations, to begin new and productive programs of nuclear research and training. The size and cost of research had ballooned beyond previous academic research. Today it may seem amusing that the budget of the Laboratory in 1940 was $66,000 and that the staff consisted of 54 people. Yet this was an unheard-of operation in fundamental physics research prior to that time.

Under Lawrence's exuberant guidance, the Radiation Laboratory came to the fore as "the foremost American school of investigators of nuclear transmutation and artificial radioactivity," in the words of the British physicist, Wilfred B. Mann. Dr. Mann recalled the flavor of the golden early days in a toast he made in London on December 27, 1940, when Lawrence was in Philadelphia to receive the prized British Duddell Medal. Dr. Mann noted:

"Usually Lawrence was himself to be found in the Laboratory from early morning until late at night; even if occasionally he did stay at home for the evening he had only to tune in his radio set to about 26 meters to know whether or not the cyclotron were still running. If there were any kind of a breakdown Lawrence would soon be telephoning to the laboratory to know what the trouble might be; and no one had the skill of Lawrence in finding the causes of such breakdowns! Nor would anything but perfect running satisfy him. If the maximum beam were not being obtained, then a period would be set aside for adjustments, in which he usually took a very active part. The Laboratory was run on a cooperative basis, members of the laboratory taking turns to run the cyclotron for the use of other members, and no visitor to the laboratory was too distinguished to do his share of the routine work if he wished to use the cyclotron . . .

". . . Incredulity is one of the most common reactions to the performance of the Berkeley cyclotrons. But to know Ernest Lawrence is to know why it is that the Berkeley cyclotrons give such incredible results. In the face of such irrepressible enthusiasm and such joie de vivre, difficulties hardly stand a chance, and faced too by his deep innate sense of physics they merely stand to fall. And in trying to appreciate that irresistable drive in the Laboratory one cannot but recall the boisterous enthusiasm of Lawrence away from work. He might return from a ski trip with an injured arm or be hobbling around the laboratory with a stick for some days after; but so soon as the opportunity returned he would launch himself as joyously as before over the brink of some snow-clad slope. One also recalls wildly happy days (equally unreal and like some far-off pleasant dream!) on some Pacific beach or in his motor-cruiser on San Francisco Bay. 'Ernest carries a chart in his boat,' one of his friends said, 'so that he'll know what mud-bank he is stranded on.' "

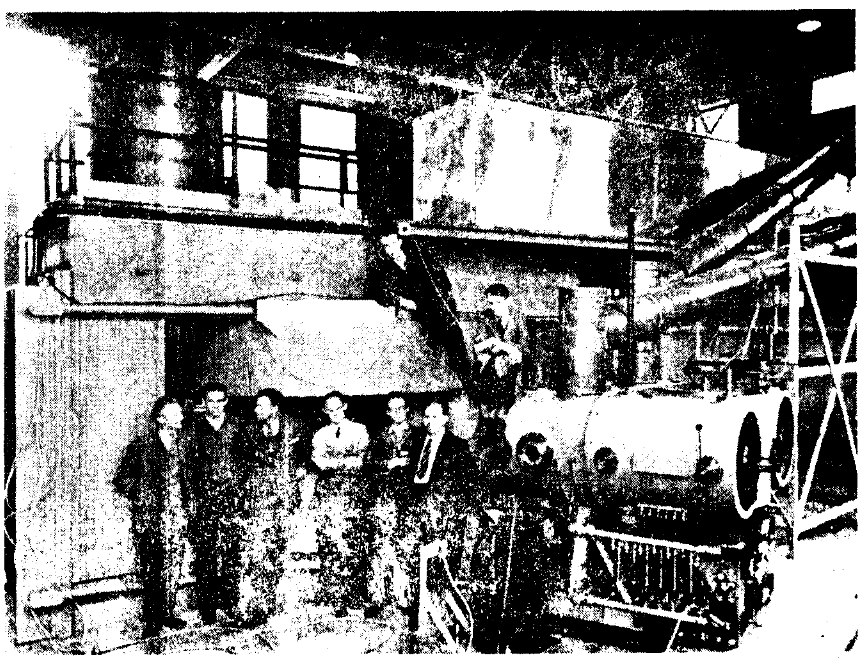
In 1939 Lawrence was selected to receive the Nobel Prize in physics for "the invention and development of the cyclotron, and for the results thereby attained, especially with regard to artificial radioelements." But with the war on and the seas teeming with U-boats, the traditional trip to Stockholm was deemed unwise. The Prize was presented to Lawrence in a ceremony in Berkeley on February 29, 1940. Not until 1951 did he journey to Stockholm to deliver his Nobel Lecture. During his lifetime Lawrence was to receive virtually every additional honor for which a physicist is eligible—the Hughes Medal of the Royal Society, the Medal for Merit, the Faraday Medal, the American Cancer Society Medal, the Enrico Fermi Award, the first Sylvanus Thayer Award, and many others. He received twenty-five honorary degrees, and was a member of the leading learned societies, many of them foreign.

Only a few of the young men attracted to Berkeley can be mentioned. Three were later Nobel Laureates: Edwin M. McMillan, Lawrence's successor as Director of the Laboratory, who, with P. H. Abelson, discovered element 93; Glenn T. Seaborg, now Chairman of the Atomic Energy Commission, the co-discoverer of element 94 (plutonium) and other transuranium elements; and Emilio Segre, discoverer of the first artificial element, technicium, and later co-discoverer of the antiproton. There was the versatile Luis Alvarez, discoverer of tritium and helium-3; Dr. Joseph G. Hamilton, pioneer of radioisotope tracer studies in man and the use of radioiodine in diagnosis and therapy; the late Samuel Rubin and Martin Kamen, discoverers of carbon-14 and originators of tracer studies in photosynthesis, using carbon-11. Dr. John Lawrence remained, initiating therapy with radioisotopes (phosphorus-32 for leukemia and polycythemia) and founding the Donner Laboratory.

Lawrence's last major pre-war scientific undertaking was the conception of a gigantic cyclotron—a 184-inch machine to accelerate deuterons to about 100 Mev, the upper limit of energy with the knowledge then at hand. He thought it was just possible that with such energies mesons could be created in the laboratory, or that a reaction might be discovered that would provide an easier alternative to fission for the practical release of nuclear energy. With a grant of $1,250,000 from the Rockefeller Foundation and funds from other sources, bringing the total to $1,500,000, construction began in the fall of 1940 on Charter Hill overlooking the campus.

Meanwhile war began and to many it seemed only a matter of time until the United States would be involved. Lawrence helped organize the radar project at M.I.T., inducing McMillan and Alvarez to work at Cambridge beginning in the fall of 1940. He played a similar role in establishing the sonar development for antisubmarine warfare at San Diego, starting in 1941.

Lawrence was not initially a member of the inner councils of the atomic bomb project, but by early 1941 he and a few other scientists became alarmed by the slow pace of the uranium work. "The central figure in the growing discontent was Ernest O. Lawrence," wrote Richard G. Hewlett and Oscar E. Anderson, Jr., in "The New World, 1939/46"—the first volume of the official history of the U. S. Atomic Energy Commission. "The inventor of the cyclotron . . . found himself pressed to do something . . . By March, 1941, Lawrence was ready to ask questions, even if it meant going out of channels. But his concern was not strictly a political matter. More than anything else, this



Photograph shows the 60-inch cyclotron at the University of California's Lawrence Radiation Laboratory, Berkeley, soon after its completion in mid-1939. In the photograph are key figures in the development and use of the machine: Standing, left to right: Dr. Donald Cooksey, now associate director, emeritus; Dr. Dale Corson, physicist, co-discoverer of element 85; the late Dr. Ernest O. Lawrence, inventor of the cyclotron, Nobel Laureate, and founder of the Laboratory; Dr. Robert Thornton, now associate director; Dr. John Backus, physicist; Winfield W. Salisbury, electronics engineer. Top left is Dr. Luis W. Alvarez, noted physicist and group leader in the Laboratory, and Dr. Edwin M. McMillan, Nobel Laureate and present Director of the Laboratory. Dr. Alvarez leans against part of the magnet and half-sits on the housing for the coils; Dr. McMillan sits on one of the tanks holding the "Dees" inside the accelerating chamber. The copper cylinders slanting down from right carry the power for the accelerating system.

many-sided man was a physicist. His involvement stemmed directly from achievements in his laboratory."

Lawrence hammered at several themes: the lack of a concept of how to arrive at an actual weapon; the seeming preoccupation with power rather than a bomb; the small scale of the project; and, above all, excessive concern with technical difficulties. Lawrence, the boyhood tinkerer, the generator of "impossible" cyclotron technologies, lived by the motto of "the obstacles be damned."

He expressed his attitude in a letter to A. H. Compton on October 22, 1941, following a meeting of project leaders: ". . . the stakes envisaged are fantastically high . . . In our meeting yesterday there was a tendency to emphasize the uncertainties, and accordingly the possibility that uranium will not be a factor in the war. This, to my mind, was very dangerous. We should have fastened our attention on the fact that the evidence now is that there is a substantial prospect that the chain reaction will be achieved in the near future, one way or another, and that military applications of transcendental importance may follow.

"It will not be a calamity if, when we get the answers to the uranium problem, they turn out negative from the military point of view, but if the answers are fantastically positive and we fail to get them first, the results for our country may well be a tragic disaster. I feel strongly, therefore, that anyone who hesitates on a vigorous, all-out effort on uranium assumes a grave responsibility."

Lawrence and his Laboratory supported his ideas with key scientific discoveries and developments in 1941. The high energy of the 60-inch cyclotron deuteron beam (16 Mev) permitted Seaborg, the late Joseph Kennedy, and A. C. Wahl to discover plutonium-238, following a line of investigation initiated by E. M. McMillan. And the intensity of the neutron beam—greater by a factor of 10 than any other source in the world—allowed Seaborg, Segre and others to discover plutonium-239 and determine that its neutron cross-section was favorable to its use in a chain reaction.

Lawrence articulated a grand and ambitious design to develop a bomb: perfect the nuclear reactor; use reactors to manufacture plutonium; separate plutonium chemically and use it, as an alternative to U-235, in a weapon. This route to a weapon was followed with Fermi leading reactor development and Los Alamos designing the weapon. Lawrence kept his 60-inch cyclotron working around the clock to supply plutonium to microchemists on the plutonium project.

Meanwhile, Lawrence concentrated mainly on the technical problem of separating U-235 from natural uranium. He became convinced that the mass spectrograph method of Alfred O. Nier, at Minnesota, could be scaled up to industrial proportions. In November, 1941, he and his colleagues, joined by Nier, converted the 37-inch cyclotron into a Dempster type mass spectrograph. By the end of the year the method was working so well that Lawrence, with permission from the Rockefeller Foundation and the University Regents, began converting the 184-inch magnet—then nearing completion—into a giant mass spectrograph.

In developing the separation process and helping make it a success at Oak Ridge, Lawrence was cast adrift from theory, in an uncharted sea of trial-and-error technology. But it was a sea in which he navigated well—and in which he succeeded, as he had in the past.

The scientist recognized that other processes, especially gaseous diffusion, had better potential than the electromagnetic. But the difficulties were so great that there was a grave question about perfecting gaseous diffusion in time to be a factor in the war. The electromagnetic method was an insurance policy—the one sure way of getting enough U-235 for a bomb. It was a major factor in producing U-235 for the Hiroshima bomb, and was quickly overtaken in efficiency by the gaseous diffusion plant.

In the post-war period, Lawrence remained influential in nuclear defense policies. He supported development of the H-bomb, and in 1952, at the Atomic Energy Commission's request, he established a new laboratory at Livermore to do weapons and other applied research.

Meanwhile, as the war drew to a close, Lawrence made plans to return his laboratory to basic research. There were exciting new—and also expensive—horizons to be explored. It seemed unlikely that a vigorous science could be re-established on the old hand-to-mouth basis of support. There had never been a national policy of general support of basic research. Lawrence shared the feeling that the national welfare required federal financing of science. Moreover, he had a lot to offer—the 37-inch and 60-inch cyclotrons and the 184-inch magnet; and the Donner Laboratory for biological and medical research, which had been completed just prior to the war. And his young men, scattered to the winds, were eager to return and resume their research.

Although the support of basic research was not within the specific province of the Manhattan District, Lawrence persuaded General Leslie R. Groves to provide funds for the Berkeley Laboratory. Groves authorized refurbishing the 184-inch magnet as a cyclotron, construction of an electron synchrotron under McMillan and development of a proton linear accelerator under Alvarez.

During the war McMillan and V. Veksler independently discovered the principle of phase stability, circumventing the relativistic mass increase effect which appeared before the war to place a limit on the energy of cyclotrons. As a synchro-cyclotron, incorporating phase stability, the 184-inch machine produced a deuteron beam of 200 Mev on November 1, 1946. A little over a year later Eugene Gardner and Cesar Lattes used the machine to produce and identify, for the first time, man-made mesons. The era of experimental high energy physics in the laboratory had begun.

Under Lawrence's guidance and with increasing support as the civilian AEC was established, the pace of research productivity increased. The periodic table was extended through element 101—and eventually 103. A new spectrum of neutron-deficient isotopes was discovered with the 184-inch cyclotron. Dr. John Lawrence developed the treatment of pituitary-associated diseases with high-energy protons and alpha particles from the 184-inch machine. Melvin Calvin worked out the cycle of photosynthesis, using carbon-14 as a tracer—and subsequently won the Nobel Prize.

Lawrence lived to see the 6.2 Bev Bevatron—completed in his laboratory in 1954—begin a new revolution in knowledge of the nature of matter. The long-sought antiproton was discovered by Emilio Segre and Owen Chamberlain in 1955 and the antineutron in 1956. When Alvarez developed the liquid hydrogen bubble chamber and linked it to semi-automatic scanning and measuring machines and computers, the revolution picked up steam with a proliferation of new particles.

Today, the spirit of Lawrence still drives the Laboratory on. The old urge to the new horizons offered by higher energy is expressed in an intensive Berkeley design study of an accelerator of 200 billion electron volts—a range about 7 times higher than existing machines. The design study will be presented for government consideration this fall. If approved, the accelerator will be a separate national facility, the location of which is not yet determined.

In the resurgence of basic science in his laboratory, Lawrence moved joyfully, reveling in the accomplishments of his colleagues. He seldom took part in "bench work" in the postwar period. But the tall figure, the bouncing shock of hair, the half-running stride, and the intense, purposeful demeanor were familiar to the Laboratory staffs at both Berkeley and Livermore. He set aside a part of his time simply to go from one part of the complex to another, talking with his colleagues, questioning, offering help. Even in his mid-fifties the old habits prevailed; he might pop up any place at midnight to see how an experiment was going.

All through the years Lawrence's zest for life outside the laboratory remained unimpaired by his intense work schedule. In 1932 he had returned to New Haven to court and marry Mary Blumer—"Molly." In a roomy, comfortable home in the Berkeley Hills, overlooking San Francisco Bay, he spent as much time as he could with Molly and a growing brood that ultimately included two boys and four girls. After the war he bought a summer home on the beach at Balboa Island, in Southern California, where he joined his family for brief visits during the summer vacation months.

His friendships and activities were diverse. Alfred Loomis and the late H. Rowan Gaither, who became President of the Ford Foundation, were among his intimates. For a time his favorite tennis partner was "Awful Fresh" McFarlane, a candy manufacturer in Berkeley with an imaginative flair for advertising. He was fond of the good fellowship of the Bohemian Club of San Francisco, and occasionally joined his brother, John, in duck shooting in the San Joaquin Valley. He enjoyed a cocktail or highball on social occasions. At one point in the 1950's he secretly took flying lessons, much to the horror of his wife and friends when he was found out.

Lawrence's last major undertaking was a search for peace. He had been a consistent advocate of improving weapons technology in the face of threatening enemies, hoping that nuclear deterrence would "make war impossible." Arthur Compton recalled that Lawrence was the last among a wartime scientific panel to give up the idea of a nuclear demonstration as an alternative to the bombing of Japanese cities.

When President Eisenhower asked him in 1958 to become a member of a three-man committee of experts to initiate the negotiations at Geneva with the Soviet Union on the possible suspension of nuclear weapons tests, Lawrence accepted out of a deep sense of duty. The scientist was ill, and had been since 1952, with what ultimately was diagnosed as ulcerative colitis.

He had tried to slow down. He went to Florida for a rest before Christmas, 1952. His old friend, Alfred Loomis, had induced him to take up painting to occupy him while he relaxed, and he turned out a number of creditable landscapes. In 1953 he took a month's sea voyage on a supertanker to the Middle East. His stays in Balboa Island were more frequent and longer.

But the achievement of serenity was difficult. It was not Lawrence's kind of work. He could not escape the deep sense of obligation, the vision of important things to be done, and the conscience that impelled him to become involved.

The toll of the years of intense involvement under high pressure and of unrelenting physical punishment were finally too much for Lawrence's ailing body. An acute attack of colitis overtook him in the midst of the initial Geneva negotiations, in July, 1958, and he was forced to return to Berkeley. After a radical operation on August 27, 1958 in a nearby Palo Alto hospital, he failed to recover consciousness, and died that evening with his wife at his bedside.

Soon after his death, The Regents of the University renamed the laboratory "The Ernest Orlando Lawrence Radiation Laboratory." They also undertook to establish a "Lawrence Hall of Science," overlooking the laboratory, for the improvement of science teaching for youngsters. It is now being built under the direction of

Scientific Staff of the University of California Radiation Laboratory with magnet of unfinished 60-inch cyclotron in 1938. Left to right and top to bottom: A. S. Langsdorf, S. J. Simmons, J. G. Hamilton, D. H. Sloan, J. R. Oppenheimer, W. M. Brobeck, R. Cornog, R. R. Wilson, E. Viez, J. J. Livingood, J. Backus, W. B. Mann, P. C. Aebersold, E. M. McMillan, E. M. Lyman, M. D. Kamen, D. C. Kalbfell, W. W. Salisbury, J. H. Lawrence, R. Serber, F. N. D. Kurie, R. T. Birge, E. O. Lawrence, D. Cooksey, A. H. Snell, L. W. Alvarez, P. H. Abelson.

Dr. Harvey E. White, Berkeley physicist and close friend of Lawrence.

Lawrence's premature death occasioned an outpouring of grief and a groping for superlatives that might adequately describe the fallen giant. President Eisenhower expressed deep shock, saying the "loss is a tragic one for the United States and for the entire free world." Nobel Laureate I. I. Rabi paid tribute to the impact of his personality on world science and said that his introduction of research on a grand scale "marked a turning point in the history of experimental physics." Seaborg cited the debt he and scores of others owed Lawrence for the research opportunities he created for them.

Others recalled a sentence from the citation of the Research Corporation's Scientific Award of 1937, one which could not be improved upon in 1958: "His achievements stand with the great works of the ages." And his saddened personal physician, Dr. Albert Snell, mused: "He did as much work in his lifetime as five ordinary men. It might be said he put in 200 man-years of life."